THE ARC TRANSMITTER

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INTRODUCTION

The arc transmitter was the first type of continuous wave transmitter to be used in marine installations. Transmitters using alternators for the production of high frequency continuous waves were developed before the invention of the modern arc transmitter and were used at shore stations but were found entirely too bulky and unfit for marine or mobile use. The arc transmitter was found so much more practicable in this stage of wireless development than any of the others that it gained considerable favor for commercial marine work.

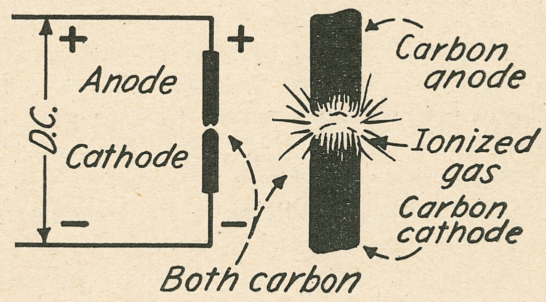


FIG. 1

Because of its adaptability for use on board ship, the arc transmitter experienced a rapid development for both marine and land stations. The fact that arc transmitter development was to some extent localized to the region of the Pacific Ocean has a peculiar significance. In this region, range requirements of 5,000 miles are quite common and as radio transmission power heretofore unheard of in marine communication was easily obtained with the practical and efficient arc converters, it was to be expected that these would be developed as rapidly as possible. The shorter distances over which communication was necessary in other parts of the world allowed the continued use of damped wave transmitters of lower power.

Before considering a complete arc transmitter, let us first learn some of the principles of the plain direct current arc.

An electric arc is the passage of electric current of relatively high intensity through a gas or vapor, the current flow mainly due to gaseous conduction from the self-heated cathode. The most common type of electric arc consists of two carbon electrodes shunted across a direct current source of power supply as in Fig. 1. The familiar electric arc was known and used a considerable time before the arc converter was invented. Electric arcs were used for welding purposes and for illumination. Self-regulating arcs are extensively employed at the present time for moving picture projectors and for street lighting. Carbon is used for electrode material because of the intense light resulting from the "arc flame." Because of the extremely high temperatures of the arc flame, the principle is used extensively in electric welding. In an arc converter for a radio transmitter, however, the arc is not used either because of its heat or because of its light, but an entirely different property of the arc is used, the explanation of which must be postponed for a few moments.

In order to put an ordinary arc into operation the two carbon electrodes are brought in contact with each other and then quickly separated a short distance. Current flow of considerable magnitude continues across the air gap between the arc electrodes. The arc gap is the spacing between the two ends of the electrodes and its resistance is very low when in operation because of the ionized condition of the gases in the gap and also because of the formation of a carbon gas in the arc gap. The oxygen in the air makes possible the combustion of this gas, and the resulting flame radiates considerable heat and light. Since the arc resistance is only slightly greater than a direct short, a series resistor is almost always used in the arc circuit.

When the arc is in operation both electrodes slowly disintegrate, the positive electrode being consumed more rapidly than the negative one. If the arc electrodes are enclosed in an air-tight chamber, disintegration can be slowed down considerably. The oxygen in the air is responsible for this disintegration—the wasting away of the electrodes—and when oxygen is excluded from the arc gap the life of the electrodes is extended materially, although the light and heat from the arc are reduced.

An electric arc is not dependent on the type of current used—either direct or alternating current will arc. The necessary condition for an alternating current arc is that the ionized gas forming the arc gap remain at a fairly constant temperature when the alternating current passes through zero value.

In this case quite naturally the consumption of each electrode is the same because each electrode is alternately positive and negative.

The wearing away of the electrodes in a D. C. arc is not uniform, but irregular. The positive electrode (anode) becomes pitted in the center, gradually rounding off at the edges, while the negative electrode (cathode) wears into a conical point.

Reasonably low D. C. voltages will operate an arc successfully. It must be understood that the resistance of the arc gap, before the arc flame takes place, is extremely high, in fact, so high that the voltage normally applied to the arc electrodes could not possibly cause current to jump the gap. The ionized

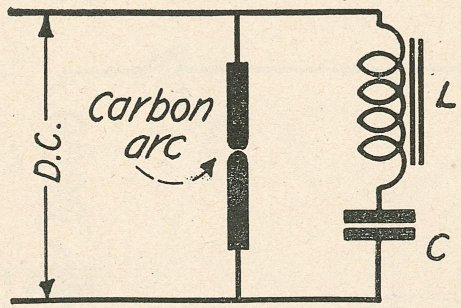


FIG. 2

gas formed after the arc has been started is responsible for low arc resistance and high current flow.

THE SINGING ARC

The principle of the oscillating arc was discovered entirely by accident as were many other fundamental principles of electricity and Radio. A series resonant circuit was placed across the arc electrodes in an early experiment, as in Fig. 2. The arc was started and a "singing" sound was produced which was in the form of a high, steady tone. It was later found that the frequency of this tone was determined by the inductance and capacity values of the series resonant circuit.

This principle was later used in the production of radio frequency current, the action of which will be described. First let us consider the effect of the series *LC* circuit alone connected directly across a D. C. source of supply as in Fig. 3. The instant the switch *Sw* is closed, current will rush into the condenser and charge it. But the charging current is limited by the

inductance L. The magnetic field formed around the coil L will oppose the flow of current and, therefore, considerable time will be required for the condenser to be fully charged.

After the condenser is charged to a point where the voltage across its terminals equals the line voltage, no more charge can take place from the line potential. But when this charging current stops flowing the magnetic lines of force around the coil collapse, building up another voltage almost equal to the line voltage. This latter voltage is impressed on the condenser in series with the line voltage and in such a direction as to add to it, thus making the total voltage across the condenser almost twice the line voltage. The condenser, therefore, receives an increased charge. When the magnetic field about the coil has

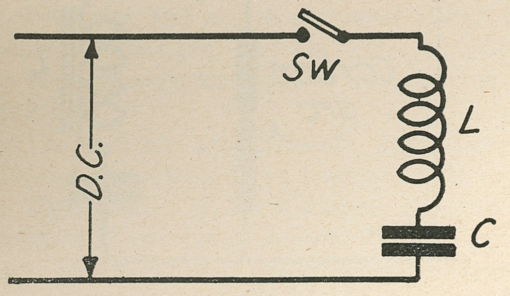


FIG. 3

entirely collapsed and the condenser has a voltage across its terminals considerably higher than the line voltage, the condenser forces current back into the line.

The action may be compared to a battery being charged. The charging voltage must be greater than that of the battery in order for charging to take place. If the line voltage falls lower than the battery, the battery will discharge into the line.

The tendency of the condenser is, of course, to discharge until its voltage equals that of the line voltage. It is discharged, but the discharged current must flow through the coil L. The coil then gains magnetic energy from this back current flow which continues the discharging action of the condenser, bringing its voltage considerably below the line voltage. As soon as this happens the line voltage attempts to charge the condenser again to its own potential and one cycle is completed. The action is oscillatory and other cycles will continue each having a smaller amplitude than the preceding one until the resistance of the circuit completely dissipates the excess energy which was alter-

nately stored in the capacity of the condenser and the inductance of the coil.

You will notice, undoubtedly, that the above explanation is simply a repetition of the well known theory of oscillatory current flow. The speed, or rate, at which this condenser charges and discharges is determined by its capacity and the value of the inductance just as in any oscillatory circuit.

The graph in Fig. 4 shows this action clearly. It will be noticed that when the switch is closed, the line voltage reduces immediately and current begins to flow into the condenser.

When the condenser has been charged to a point where its back e.m.f. is equal to the charging e.m.f. (c on curve E_c), current continues to flow into it due to the collapse of the field

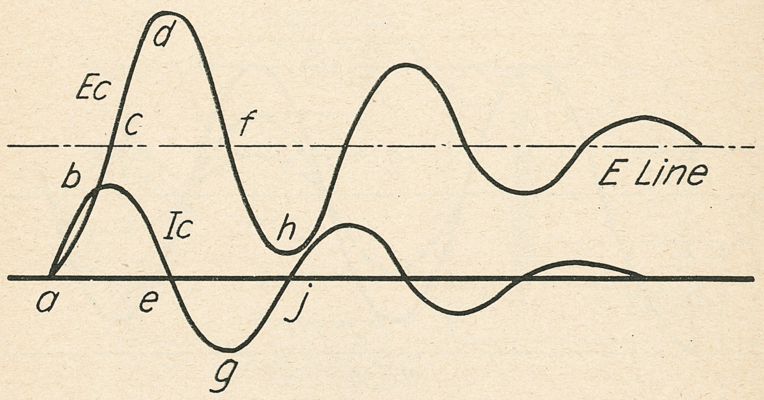


FIG. 4

about L. When the field about L has collapsed entirely, the current in C is again zero instantaneously (e) and the voltage across the condenser is maximum (d). As the condenser charge is higher than the line potential the condenser discharges into the line through the inductance, building up another field about L. Again the inductance prolongs the flow of current from the condenser and the condenser current goes through g to j, at which point the condenser voltage is lower than that of the line (h). And in this way the current swings back and forth between the condenser and the coil until the resistance of the circuit damps out oscillation.

When oscillation dies out the condenser voltage is equal to the line voltage and no current flows in the circuit. The condenser terminals are always of the same polarity determined by the polarity of the D. C. line, but it must be carefully noted that

current in the *LC* circuit is A. C. in character, and this A. C. "rides on" the D. C. of the line.

Now, let us suppose that, instead of having a source of constant voltage, the applied voltage could be increased or decreased at will. Here is what would happen—see Fig. 5. If the terminal voltage were kept constant (e_1), after the voltage across the condenser had increased to *b* it would decrease to *c* which is not as far below the line voltage e_1 as *b* is above it. Circuit losses prevent the voltage from reducing to *d*. Notice that this action is identical with the action just described.

During the time that the voltage is decreasing from *b* to *c* suppose that we decrease the line voltage e_1 to a lower value e_2. Now the total condenser voltage will be equal to *d* instead of *c*. It will be noticed that *d* is as many volts below the original line

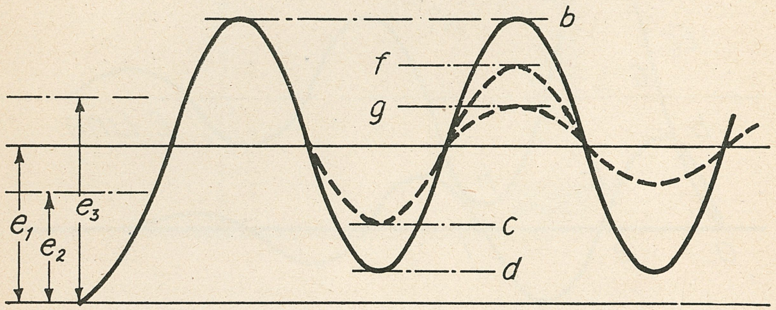


FIG. 5

voltage e_1 as *b* is above it. When the condenser voltage increases again, its maximum value will be increased to *f* instead of to *g*. Now if the line voltage is raised to e_3 the condenser voltage will rise to *b* which represents the same amplitude as the original charge. In the same way, all succeeding amplitudes are made equal to *b* and sustained oscillation results.

Thus, by increasing and decreasing the voltage of the supply line at exactly the proper time, the *LC* circuit can be made to oscillate continuously. But this is not sufficient for radio purposes because as soon as energy is taken from the *LC* circuit by another circuit coupled to it in some way, or as it is commonly expressed, a large load resistance is placed in the *LC* circuit, the amplitude of its oscillations will diminish considerably.

It is quite possible, however, to increase and decrease the supply voltage considerably beyond the values necessary to

sustain oscillation in the *LC* circuit. When this is done energy in the circuit will build up to a very high amplitude so that when energy is drawn from it, its amplitude will increase to take care of this additional energy just as the current through the primary of a transformer will increase to take care of the secondary load. Of course there is a limit to the amount of increase of this energy, determined by the efficiency of the device and the power available.

This principle is the principle on which the arc converter operates. The variation is entirely automatic and is produced by the action of the arc. It is a known fact that the higher the voltage across the arc the less will be the arc's current; if we were to rob the arc of some current the arc terminal

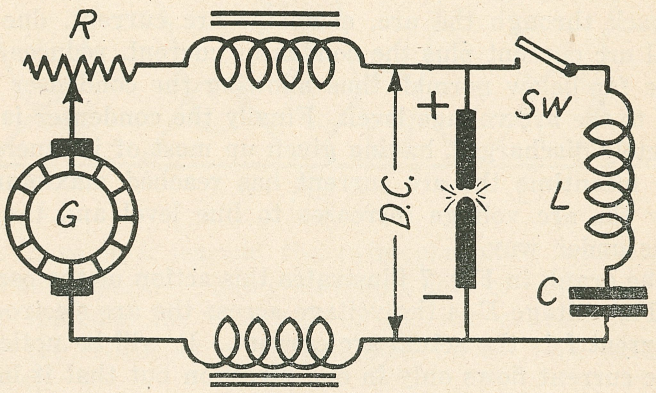


FIG. 6

voltage would go up. Again if the arc voltage is lowered the resistance will go down and consequently the arc current is boosted; if in some manner the arc were fed additional current, its terminal voltage would go down.

Let us now review these principles in an actual transmitting arc converter, a diagram of which is shown in Fig. 6. The switch *Sw* is thrown after the arc is operating. Before *Sw* is closed the arc voltage is somewhat lower than the line voltage at the generator. This is brought about by the voltage drop across the resistor *R* in the main arc line.

The condenser *C* immediately charges, at first lowering the arc current. As current is drawn from the arc, thus robbing the arc of current the arc voltage increases. Because of the choke coils the current from the generator cannot increase rapidly and if current is to be drawn by the *LC* circuit it must

be drawn from the arc, as additional current cannot be drawn from the generator instantaneously. The current simply divides and a great deal of it rushes into the condenser instead of across the arc. If there were no chokes, the generator could probably supply the *LC* circuit with the necessary current and the arc current would not be disturbed. Under these conditions the arc voltage would remain practically constant and the necessary voltage changes would not occur.

The condenser charges to amost double the average generator voltage; the choke coils again come into action and prevent the current from the discharging condenser from flowing back into the generator, forcing it to take the path through the arc. This is desirable because it automatically lowers the voltage of the arc. Then when the excessive condenser voltage forces current back through the arc, excessive arc current, due to the normal arc current plus the condenser current, reduces the arc voltage far below normal, thus allowing the condenser voltage to fall to the arc voltage level. Finally the condenser is almost completely discharged, having given up most of its energy, and in the meantime the arc current has reached maximum. Instantly the arc voltage increases to line level and the second cycle is under way.

The graph in Fig. 7 illustrates this action of the oscillating arc. The voltage E is the voltage across the arc electrodes and the current I is the actual arc current. It will be noticed that the arc current flows only in one direction but that it increases to almost twice its normal value and decreases to nearly zero. The voltage also increases to nearly double normal and decreases to almost zero. When the arc voltage is highest the arc current is lowest and vice versa.

If the change in voltage of the arc is more than is necessary to overcome the resistance of the *LC* circuit, energy can be taken from it (*LC*) and it will continue to oscillate. For this reason the arc is said to have a negative A. C. resistance. Do not take this to mean that the A. C. resistance of the arc has actually been reduced below zero because this is only a theoretical term. Any circuit which sustains oscillation must have zero resistance. When we draw power from a circuit, we are in effect adding a load to that circuit, or inserting a resistance. Thus when we draw oscillating power from an arc circuit we add a resistance. Yet oscillation is sustained so the circuit must under this condition have less than zero resistance. If the load added x ohms, and there are still oscillations, we can

say that the arc supplied $-x$ ohms, as $+x$ plus $-x$ equals zero resistance.

From this very detailed explanation of arc action, it is clear that the arc is simply a means of controlling the applied voltage before it is supplied to the *LC* circuit, and that this controlling action is entirely automatic for the arc is itself controlled by the *LC* circuit. Thus one is dependent on the other—but for all practical purposes we can say that the oscillatory circuit automatically helps itself to the voltage required for proper oscillatory action.

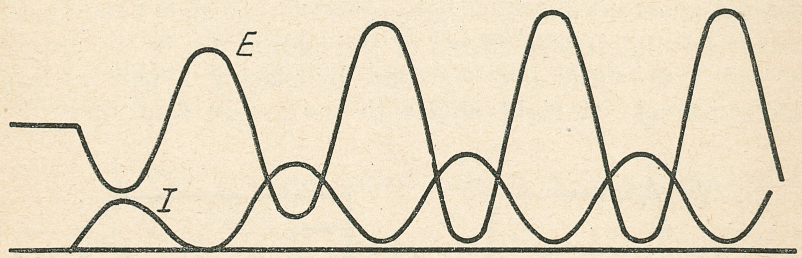


FIG. 7

We have now learned the principles upon which all arc transmitters operate. Many auxiliary devices have been developed to increase the efficiency of the arc converters and to increase the frequency of the radiated waves. We shall study these next.

BLOW-OUT MAGNETS

Since the frequency of alternating current produced by the arc converter depends entirely upon the values of L and C used in the oscillatory circuit it would seem that these two could be given nearly any values and that the arc would produce a frequency corresponding to their resonant frequency. It was found, however, that the first oscillating arcs would not function at frequencies much in excess of 50 kilocycles, regardless of how small the values of both L and C were made. This was because the arc voltage would not change as rapidly as the *LC* circuit demanded, without reducing the amplitudes of the changes to such an extent that continuous oscillation would not be maintained.

A careful study of this problem led to a better knowledge of arc action and ultimately to various solutions of the problem.

It was learned that the arc gap contained a considerable mass of ionized gas, which has the inherent property of "holding" its temperature and remaining in an ionized condition. This tended to keep the arc current fairly steady, preventing the arc voltage from changing to any appreciable degree. Quite naturally, the higher the frequency at which the arc is intended to operate, the more difficult will it be to effect a change in current.

At comparatively low frequencies, i.e. between 5,000 and 25,000 cycles, the arc current would be able to reduce to a considerable degree. This would enable the arc voltage to change materially and hence strong oscillation could be produced.

These undesirable effects of the ionized gas in the arc gap at high frequencies are overcome by placing a pair of large electromagnets at right angles to the arc so that there is a

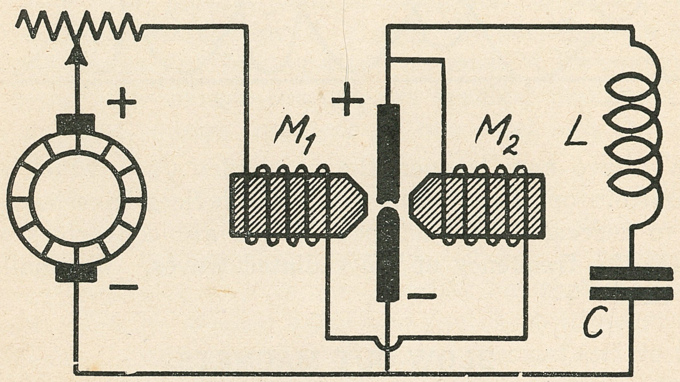


Fig. 8

strong magnetic field through the arc. These electromagnets are called "blow-out" magnets. Their function is to force the ions from the arc gap and thus clear out the gap the instant the arc voltage rises.

You can easily imagine millions of ions drifting across the arc gap from the positive electrode to the negative electrode. They of course constitute the current flow in the arc gap. A current flow is always accompanied by a magnetic field and the current flow across the arc gap is no exception to this rule. This field is of identical character to the field about a conductor.

The blow-out magnets set up a "transverse" field (that is, at right angles to the field around the arc flame) which is very intense and also constant. These blow-out magnets have small

pole tips which are placed very close to the arc flame, one being N and the other S. They are excited very conveniently from the main current to the arc which is very large.

From our knowledge of the principle of the electric motor we can see at once that a conductor carrying current (in this case the current-carrying ions) will be given a mechanical "thrust" when brought into the vicinity of a magnetic field. Because of this thrust the ions are pushed out of the arc gap.

A complete fundamental arc converter circuit is shown in Fig. 8. The blow-out magnets M_1 and M_2 are wired in series with the positive electrode lead and their coils carry all of the arc converter supply current. These magnets are very heavy and constitute the main bulk of the converter. The windings of the magnets act as chokes so that the chokes in Fig. 6 are unnecessary in Fig. 8. Thus blow-out magnets serve three purposes.

1. They prevent radio frequency from getting into the generator.
2. They provide the necessary inductance to prevent the generator from quickly acting on the arc, when the arc voltage goes up or down.
3. They clear the arc gap of ionized vapors and gases.

THE ARC CHAMBER

More stability of arc current can be obtained by introducing hydrogen gas into the chamber in which the arc electrodes are enclosed. This gas may be produced directly in the chamber by the action of the terrific heat of the arc on kerosine, gasoline, benzine or alcohol, but alcohol is used almost exclusively. The arc will also function well if surrounded by steam or water vapor. However, less sediment is deposited and better action is obtained when alcohol is used.

Due to the arc heat the alcohol vaporizes and is broken up into various chemicals, hydrogen gas being the important one, which completely fill the arc chamber and arc gap. This gas ionizes and deionizes very readily thus permitting rapid changes in the flow of current through the arc. Deionization is furthered by the use of hydrogen, because hydrogen ions "spread out" or "diffuse" very rapidly. Of course the greater the diffusion the more rapid will be deionization. At the same time hydrogen assists in the cooling of the electrodes for it has high heat conductivity.

RADIATION

We have now considered in detail a complete arc oscillator, an instrument for producing high frequency continuous *alternating* current from a direct current source. The high frequency alternating current flow, of course exists only in the coil L and condenser C of the resonant circuit. In order to radiate this energy in the form of electromagnetic waves, it is only necessary to substitute, for the condenser, an antenna-ground system having a capacity equal to the condenser capacity,

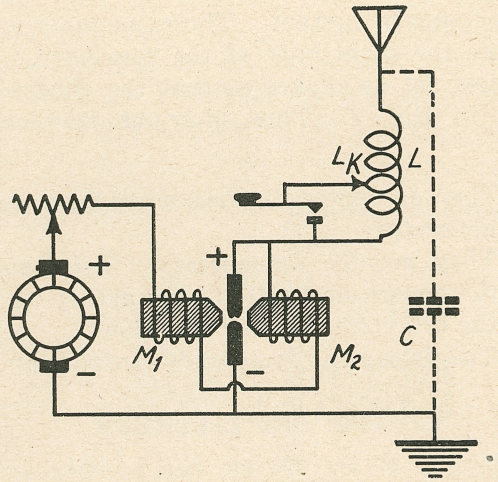


FIG. 9a

as in Fig. 9a. You will notice that the circuit is practically the same as in Fig. 6, except that the chokes are no longer necessary and have been omitted. The inductance L here is smaller because the inherent inductance in the antenna adds to L. This arc converter is directly coupled to the antenna system from which it radiates electromagnetic energy. Inductive methods of coupling as in Fig. 9b are not used except for high power as will be shown later.

ARC SIGNALLING SYSTEMS

A real problem in arc transmission is the forming of the dots and dashes necessary for signalling. It must be pointed out here that the arc is not readily started and the key cannot be placed in the main arc supply line because every time the circuit is broken, the arc electrodes must be brought in contact with each other to start up again or some auxiliary device has to be used to "re-ignite" the arc.

The first signalling system used consisted of a transmitting key shorting part of the transmitting inductance L as in Fig. 9a. The inductance was computed for the proper frequency in conjunction with the antenna-ground capacity and a closed circuit key was simply placed across a few turns of the coil. When the key is pressed, the circuit is open and the turns L_k which it shorts are included in the circuit. When the key is released, the turns are shorted again. When the turns are shorted, the effective inductance value of L is reduced and hence the frequency of the arc converter, which depends on L and the antenna circuit, is changed. Thus two different waves are sent out, one at normal frequency when the key contacts are closed, and another at a lower frequency when the key is depressed and L_k is not shorted. Continuous wave energy is always being sent out, but the key shifts the energy from one carrier frequency to the other.

If a C. W. receiver is tuned to the frequency transmitted when the key is pressed down, code signals may be heard and translated as the time length determines a dot or dash. But if a receiver is tuned to the transmitted wave when the key is not pressed, all that will be heard are the spaces between the dots and dashes of a message on the off-frequency wave. However, this method of signalling has some very serious drawbacks. Two frequency bands are required and one of the frequencies isn't used at all and so is

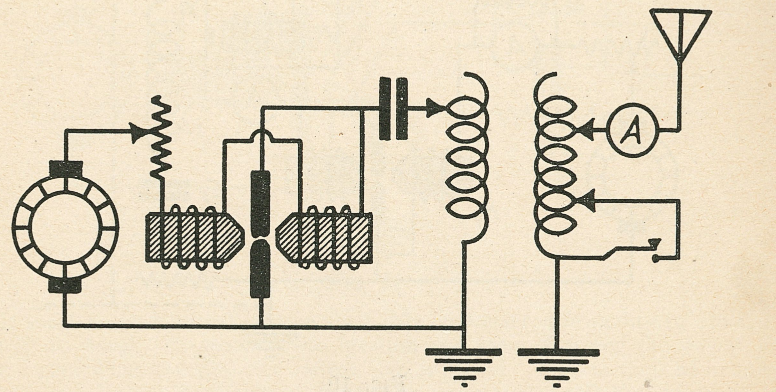


FIG. 9b

wasted. It simply takes up room in the frequency spectrum which might be well used for another channel. Then too there is considerable arcing at the key contacts, necessitating continual key replacement and endangering the operator.

Another method of keying was developed whereby the R. F. energy could be led to a "dummy" circuit which does not radiate when the key is released. Because the transmitting energy is "shunted back" to another circuit (see Fig. 10), it is called the "back shunt" signalling system. It functions as follows: Contacts *1* and *3* of relay X_1 are normally closed, thus completing the arc converter circuit L_1-C_1. You will notice that this capacity and inductance are wired exactly as in the fundamental arc converter circuit.

The arc oscillates at a frequency determined by L_1 and C_1 but no energy is radiated because the inductance and capacity are concentrated, "lumped." R replaces the antenna load, and L_1-C_1 together with R constitute an equivalent dummy aerial. In some cases, they are shielded. When the key is pressed, direct current from the power line flows through the solenoid M_2 attracting armature *1* of the "back shunt" relay X_1. This action breaks the back shunt circuit, and at the same time closes the main antenna circuit through contacts *1* and *2*.

The constants of the L_2-C_2 circuit are the same as the constants of the L_1-C_1 circuit so that when relay contacts *1* and *2* are closed, the oscillating current is exactly the same as in the back shunt circuit. Radio waves are transmitted at this frequency. The time required for the armature *1* to break contact with point *3* and make contact with point *2* is made as small as possible.

An ammeter is connected as shown so that when the key is held down, it reads the intensity of the antenna current and when the key is released, it reads the intensity of the back shunt current. Not only should the frequency of these two circuits be identical, but their current flow values should also be identical. The resistor *R* is for the purpose of adjusting the intensity of

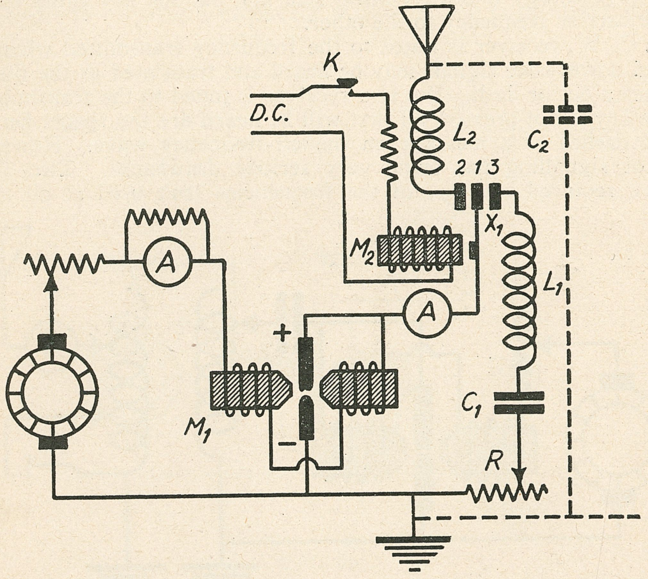


Fig. 10

current flow in the back shunt circuit so that it can be made equal to the antenna current without materially changing its frequency. The relay action takes place so quickly when the key is pressed and released, that no change in reading of the ammeter can possibly be noticed. Therefore, *R* should be adjusted with the key open.

This signalling system has many advantages over the first method. Only one channel is required for transmission, the arc functions continuously and the change from one circuit to another is made so rapidly that practically no arcing occurs across the relay contacts.

IGNITION KEY SIGNALLING SYSTEM

Another form of signalling is employed in arc transmitters in which the arc is entirely stopped and started while keying. When the key is pressed the arc is "ignited" and when released the arc stops. Because of this ignition starting of the arc, the system is called the "ignition key" signalling system. An additional small arc, consisting of electrodes *A* and *B* in Fig. 11, is placed adjacent to the main arc. The two arcs are in parallel except for the resistor R_2 which is used to reduce the current to the smaller arc. The small anode

A is stationary but the cathode *B* is in an iron holder which is mounted in a solenoid M_2 in such a way that it is free to move in the direction of its length. Normally the anode *A* and cathode *B* are held in contact by a spring but when the key is pressed the D. C. flows through the solenoid M_2 forming a magnetic suction effect which draws the iron holder and the cathode *B* away from *A*. An arc is thus formed. Now if the main electrodes are not cold the blow-out magnet will draw the ionized gas from the small ignition arc between the large arc electrodes and thus ignite the main arc putting out the smaller one.

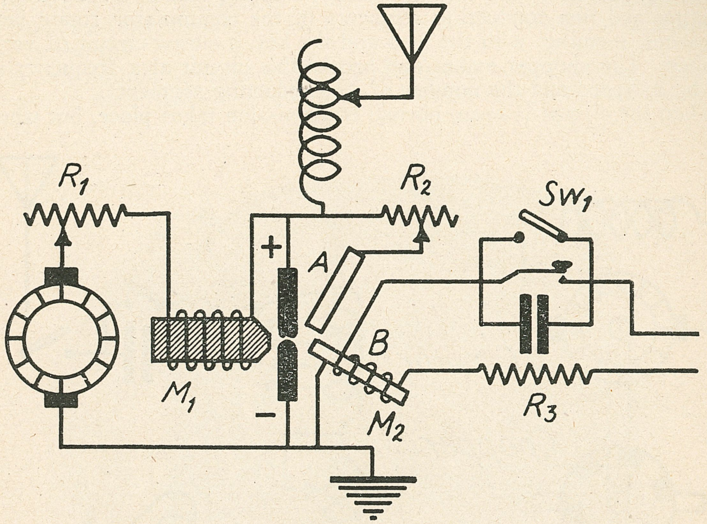


Fig. 11

It must be understood that to start this converter, the main arc must be "struck" as usual. To prevent the ignition arc from shorting the power of the main arc when starting, the switch Sw_1 is closed. This is shunted around the key and keeps the ignition electrodes separated until the operator is ready to transmit.

When the main arc is sufficiently warm so that it will re-ignite easily, no trouble will be had in keying. Enough of resistor R_2 remains in the circuit to reduce the contact current through the ignition electrodes so they do not overheat. The arc ignition mechanism may be made sufficiently light and flexible so that rather high signalling speeds may be attained.

The disadvantages of this signalling system are numerous, and for this reason it is not in common use. The time required in starting the arc is too great. Transmission must be continuous because if the key is released for more than 15 or 20 seconds the main arc will not re-ignite and the entire starting process will have to be repeated. The mechanism is complicated, requiring frequent adjustment and replacement of the ignition electrodes. For these reasons, the back shunt system is used almost exclusively.

COMPENSATING WAVE SIGNALLING

Although C. W. transmission has many advantages from a transmitting viewpoint, only heterodyne receivers can receive C. W. signals. In order that other types of receivers can handle the signals, the C. W. must be broken up (interrupted) at the transmitter.

One method of doing this is shown in Fig. 12. It employs a so-called "compensating wave" keying circuit which accomplishes practically the same thing as shorting part of the antenna inductance in Figs. 9a and 9b. A single loop called the compensating loop is inductively coupled to the lower antenna tuning inductance. The circuit containing this loop is made continuous through a key, a double pole single throw switch and a chopper commutator. A small direct current motor which draws its current from the main line, drives the chopper.

The chopper is made up of alternate segments of conductive and insulating material and all of the conductive segments are connected together. The conducting and non-conducting segments of the commutator rotate between two brushes, forming, with the loop and the key, a closed circuit of very low resistance. The chopper makes and breaks this circuit at a frequency determined by its speed and the number of its conducting segments.

When the circuit is open, normal transmission takes place, but when the

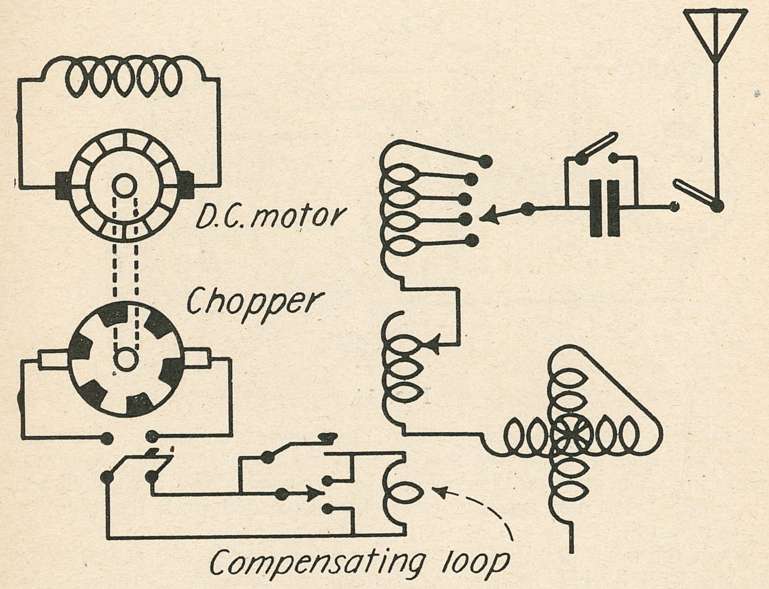


Fig. 12

circuit is closed, the antenna sends out a "compensating" wave off its normal frequency. If the chopper interrupts the circuit 500 times per second, the antenna will be changing its frequency of transmission from normal to a higher frequency 500 times per second. For reception of these signals, a receiver may be tuned to the natural wavelength of the transmitting antenna, the frequency which would be radiated with the key closed. Before the key is pressed, a non-regenerative receiver will not respond at all except for a click at the beginning and end of keying and a heterodyne or regenerative receiver will "pick up" the usual heterodyne squeal. When the key is pressed, the non-regenerative receiver will respond to the frequency of the chopper and the heterodyne receiver will receive both the heterodyne whistle and the frequency of the chopper.

The signal is broadened out by this type of signalling system so that any receiver may be tuned to either the normal or compensating wave frequency with equally good results. With the chopper rotating and the key up, the

transmitter is sending out only one wave. But, when the key is pressed, it sends out two waves alternately, first at one carrier frequency and then at some higher frequency.

NODAL POINT KEYING

When the power of the transmitter exceeds 5 kilowatts, a method of keying altogether different from any of the methods already described must be employed. The circuit is now as shown in Fig. 14. The method of keying used in this type of transmitter is very unique because advantage is taken of a resonance phenomenon which has not been considered in any other arc transmitter so far.

There is nothing unusual about the process of "side-tracking" the energy of the arc in accordance with the keying so that energy is only being radi-

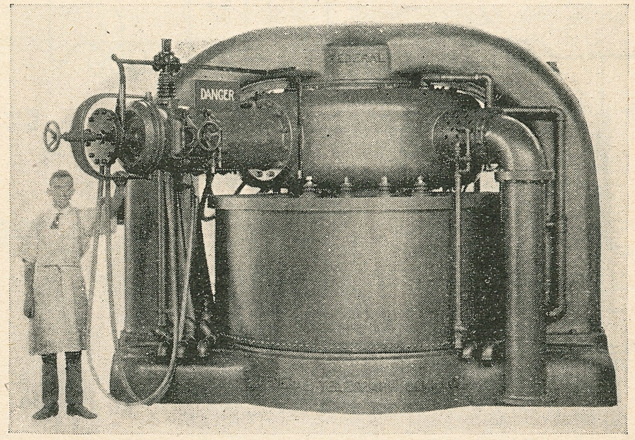


Fig. 13
Federal 1000 kw. Arc Converter

ated while the key is pressed. The dummy circuit, which will be referred to in this system as the "resonator" circuit, consists of the inductances L_1 and M_1 and the capacity C_1. M_1 is only a small loop and its purpose here is not to add to the inductance of the circuit but it is used for a reason to be explained shortly.

The combination of L_1, C_1, M_1, M_2, L_2, and C_2 forms two resonant circuits in series, both resonant to the same carrier frequency. The point N joining these two resonant circuits is the electrical "center" of the complete circuit, that is, it can be connected to ground and L_1, M_1 and C_1 will still resonate at the same frequency. It may be considered as being at *ground potential at all times*. The point N is referred to as the *nodal* point of the circuit. The shorting of the point N to ground, prevents current from flowing in the aerial resonator circuit M_2, L_2, C_2 and prevents radiation except for a very slight leakage which may have been induced indirectly from the L_1-C_1 circuit. This leakage current is neutralized out of the antenna by means of coils M_1 and M_2 which are 180° coupled (that is, coupled so that M_1 induces a current into M_2 just large enough to balance out the leakage current).

Transmission is accomplished by pressing the key which opens the con-

nection NXG connecting N to ground and leaving R_2 in the circuit. Since the antenna circuit M_2-L_2-C_2 is in resonance with the arc supply, the only effect on the total arc circuit is the addition of the antenna radiating resistance. This antenna resistance is very low and shunts R_2 which has so high a resistance that most of the energy will go into the antenna circuit. For example, in any circuit containing two resistances in parallel, the total load current will distribute itself so that the lowest resistance will pass the largest amount of current. By using a high resistance for R_2 most of the load in handled by the antenna and still the presence of R_2 prevents shifting of the nodal point. Now when the key is released, R_2 is shorted and all of the arc energy is confined to the local circuit except a slight leakage which is neutralized by coils M_1 and M_2.

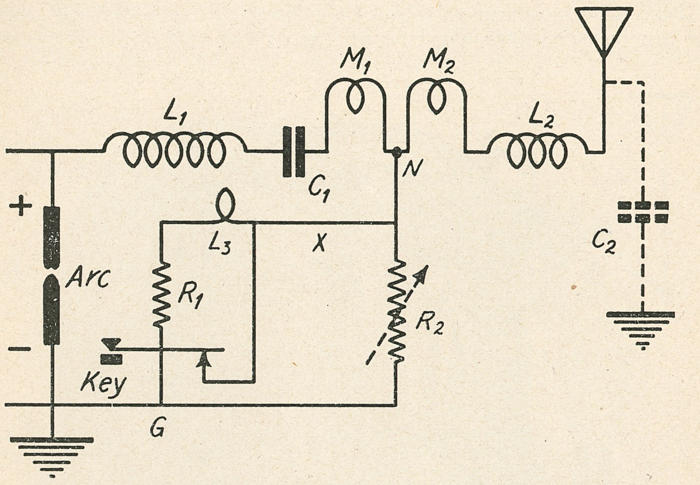


FIG. 14

Unless the same current is drawn from the arc when the key is open as when it is closed, the system will be unbalanced. When the key is opened, high current will develop in the key circuit M_1-L_1-C_1 because at resonance this circuit has zero impedance. A loop L_3 and load resistor R_1 are designed to supply a load in the circuit M_1-L_1-C_1 thus increasing the local load to match the output load when N is grounded through R_2 and the antenna is radiating. The load added to this circuit when the key is closed is exactly equal to the load added to the antenna circuit by the resistance R_2 when the key is opened. Incidentally, the loop L_3 changes the frequency of the local circuit slightly, throwing it out of resonance with the radiating system and lessening the chance for leakage radiation.

The key is not placed in any high potential circuit thus allowing high speed keying without breaking any line carrying heavy current.

TUNING THE TRANSMITTER

Arc transmitters are used for all commercial work carried on between 600 and 1200 meters. They must therefore be variable through these wavelengths with the proper tuning facilities.

A diagram of the antenna circuit of the arc transmitter

using the back shunt signalling system is shown in Fig. 15. The complete antenna system consists of a condenser, two tuning coils, a variometer, a resistor, an ammeter, the arc and the ground connection. The function of the condenser is to shorten the natural wavelength of the antenna system so that it will have high radiation efficiency at the higher frequencies. The function of the tuning coil (the loading inductor) which is tapped, is to obtain, for every definite value of inductance, a definite radiating frequency.

Another inductance coil is used so that the compensating loop may be coupled to it and so that the inductance may be varied to a still finer degree. However, the wave is so sharp that other methods of tuning are necessary in addition to these two tapped inductances. Although its range is not great,

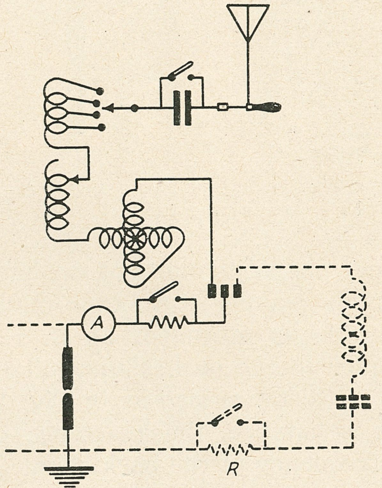


FIG. 15

the variometer forms a continuously variable inductance by which very fine wavelength changes may be made while keying to spread the signal slightly.

There is no way to reduce the power of the arc transmitter except by placing a resistance directly in the antenna circuit. It is often necessary in commercial ship work to reduce the power of the transmitter when approaching port and the antenna resistor and switch are provided for this purpose. The antenna ammeter gives a definite indication of radio frequency current flow at any time and therefore the degree of radiation.

With the back shunt signalling system, means must be pro-

vided so that the back shunt circuit may also be tuned, for as you know it must duplicate exactly the antenna radiating circuit. Its frequency should correspond exactly to that of the antenna for best results, and as you know, this frequency may be anything corresponding to 600-1200 meters.

Two methods are commonly used for this tuning. One method employs a steel or iron disc mounted near the field of the back shunt coil, as in Fig. 16. It is securely mounted on a threaded shaft so that its distance from the coil may be varied, thus reducing the inductance of the coil as the disc is brought nearer to it. This in turn will vary the frequency of the back

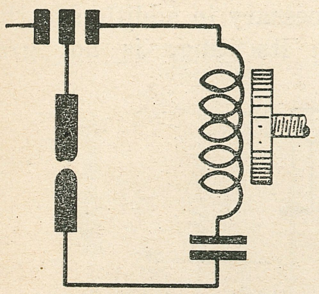


FIG. 16

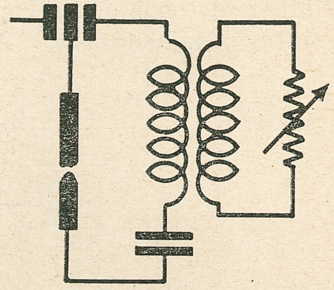
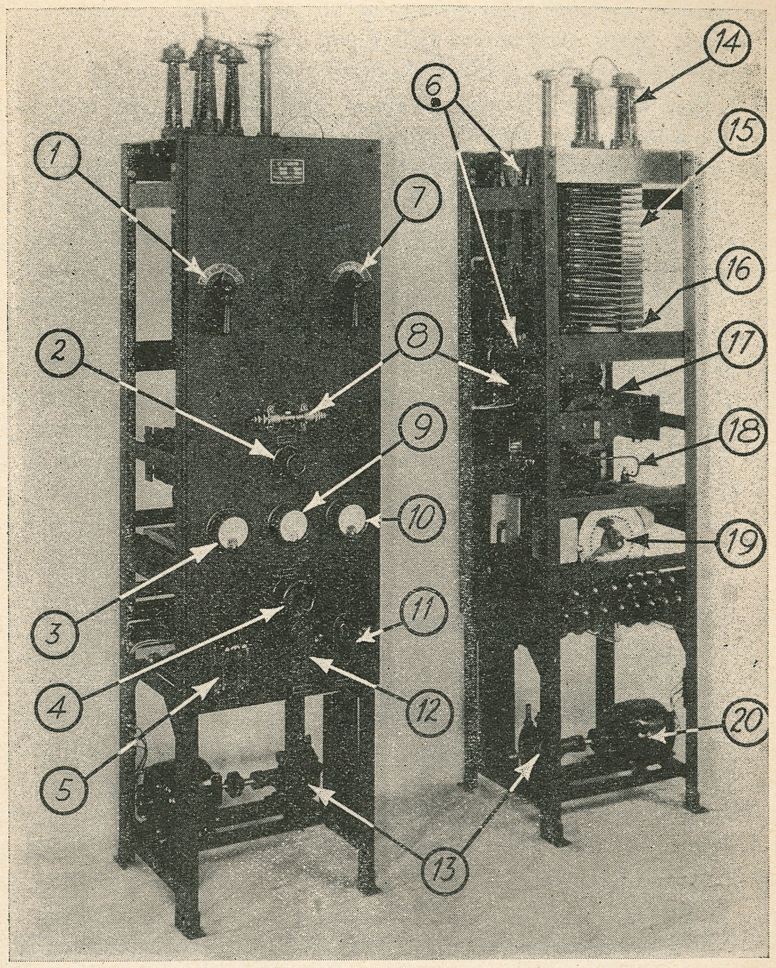


FIG. 17

shunt circuit. Very fine adjustment of the back shunt frequency can be made in this manner. Another method of tuning the back shunt circuit is by means of an R. F. transformer. A secondary is coupled to the back shunt coil and this secondary is provided with a resistance load as in Fig. 17. By decreasing the value of the resistance, the reactance of the primary is lowered and the frequency of the back shunt circuit is increased accordingly.

MECHANICAL FEATURES OF THE ARC

To prevent the electrodes from "burning" unevenly, the carbon cathode is slowly rotated by a small auxiliary motor. The arc electrodes in this way will wear away evenly all the way around and thus maintain a constant arc gap until readjustment for spacing is necessary. The positive electrode or "anode" is usually made of copper instead of carbon. If artificial means were not employed to cool the anode it would melt in a very few seconds due to the extreme heat of the arc flame.



2 kw. Arc Transmitter Panel, front and rear

1. Antenna change-over switch
2. Reactor disc adjuster knob
3. Arc current ammeter
4. Dummy circuit resistor knob
5. Main line supply switch
6. Antenna inductance taps
7. Wavelength adjustment lever
8. Back-shunt relay
9. Radiation ammeter
10. Arc voltmeter
11. Arc main line switch
12. Arc starting resistor switch
13. Chopper
14. Antenna lead insulator
15. Antenna inductance (multiple pie)
16. Compensating loop (pie)
17. Dummy circuit inductance
18. Dummy circuit capacity
19. Dummy circuit resistor
20. Chopper motor

For this reason the anode is provided with a water jacket through which chemically pure water is constantly circulated. The anode is also provided with a removable tip so that it can be replaced when eaten away as there is some decomposition at the arc flame surface of this electrode.

Arc converters of most modern design use copper for both electrodes. Both are water cooled and the cathode is rotated. The electrodes are either mounted directly in line along the same axis or at right angles, the arc gap being at the approximate midpoint of the arc chamber. The upper and lower surfaces of the arc chamber are water-cooled bronze plates. The tops of small converters (from 2 to 5 kw.) open on hinges to allow cleaning and inspection of the chamber. The spacing of the electrodes remains at 1/32 of an inch until the arc is operated. The electrodes are touched and then separated as far as possible without extinguishing the arc flame, by turning a knob. Some experience will be necessary to determine just how far the electrodes may be separated. If the arc goes out it will be necessary to strike it once more.

A TYPICAL ARC TRANSMITTER

The model "Q," 2 kilowatt arc transmitter is the type generally installed on merchant vessels using arc transmitter equipment. The model "K" arc transmitter is used on vessels of the U. S. Navy and need not be considered here.

Fundamentally an arc transmitter installation includes five distinct divisions. First, the storage battery and auxiliary equipment; second, the motor-generator set with its starting and operating controls; third, the arc converter or main arc oscillator; fourth, the antenna circuit equipment including several auxiliary devices; and fifth, the receiver. No trouble will be had in discerning these five distinct units in the diagram of Fig. 18.

The charging panel for the arc transmitter installation is identical to that used for the spark transmitter or for the vacuum tube transmitter, and a detailed discussion of its operation will be taken up in a later text. Briefly this auxiliary or emergency equipment consists of an input polarity reversing switch, an overload-underload relay, a bank of charging resistors, a couple of float lamps, and a six pole double throw switch whereby the main arc may be run directly from the line or may be run from the storage battery.

A motor-generator set (MG) is essential for converting the ship supply of 110-120 volt D. C. line voltage to a potential of 250 to 400 volts D. C. needed for the arc. The motor M is a shunt wound motor and is hand started. The generator field

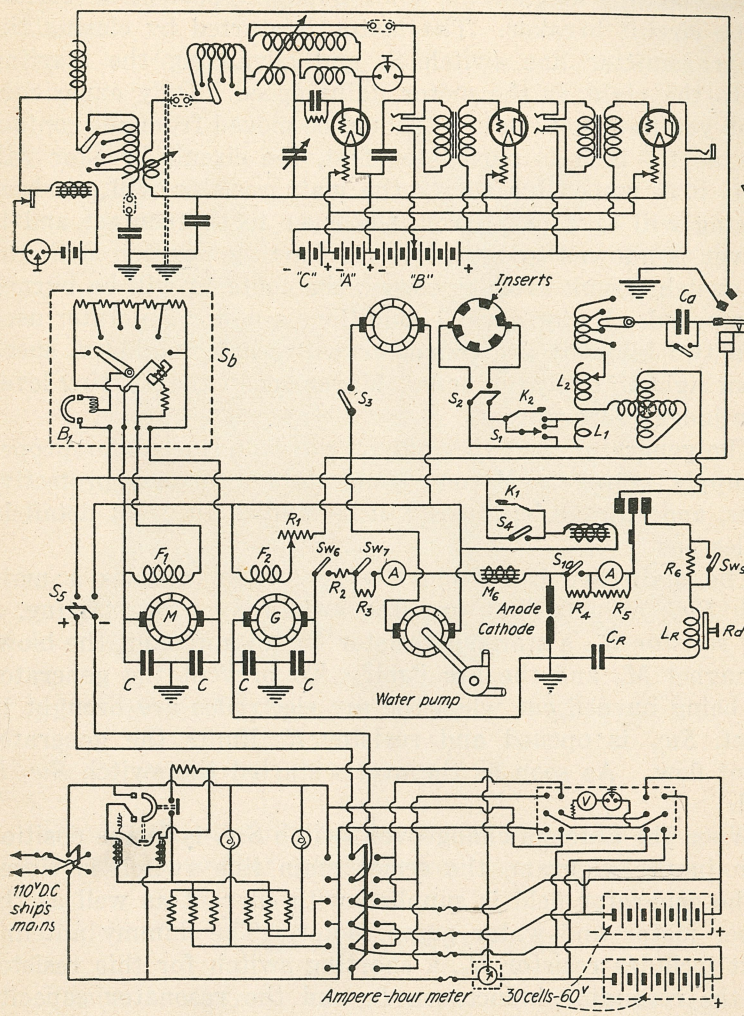


Fig. 18

F_2 is externally excited from the 110-120 volt D. C. supply line through a field rheostat. The armature protective condensers (C) are shown on both the motor and the generator. A circuit breaker B_1 is included in the hand starting box so that the line will be protected in case the starting handle is advanced too

rapidly or in case the arc electrodes are shorted for too long a time.

The motor starting box S_b includes the main starting resistance with contacts, an auxiliary field resistor, the starting lever, the holding magnet, the holding magnet protective resistor and the circuit breaker. The motor is started by closing the main transmitter line switch S_5 and advancing the starting lever to the right as the motor gains speed. Only experience will tell you how fast the lever should be moved from one contact to the next. If it is moved too fast, the circuit breaker will trip; if it is moved too slowly the main resistor will overheat or arcing will take place from the lever to the contact and if the lever is allowed to return to its starting position with the main switch circuit breaker closed, the contacts will be burned and damaged. Under normal conditions a motor-generator used with a two kilowatt arc converter will reach maximum speed in from eight to twelve seconds. Movement of the starting lever can be judged accordingly.

The generator field rheostat R_1 can be adjusted for proper arc supply voltage. Motors, generators, starters, protective devices, and storage batteries will be studied in great detail in later lessons.

The main arc line from the generator includes a main switch Sw_6, an auxiliary arc line switch Sw_7 for starting, a series resistor R_2, a starting resistor R_3, an ammeter, the blow-out magnet M_6 and the arc itself. To prevent the generator from being burned out when the arc electrodes are brought in contact, Sw_7 is opened and resistor R_3 limits the generator current flow. As soon as the arc is started the switch Sw_7 is closed.

When the antenna changeover switch Sw_8 is in the position shown in the diagram, the series main line switch is closed and the generator field is supplied with current as well as the chopper motor and water pump motor. The dummy antenna circuit includes resistor R_6, a shorting switch for this resistor Sw_9, the resonator inductance L_r and the resonator capacity C_r. The switch Sw_{10}, the resistor R_4, the ammeter and the center key relay contact are all included in both the main radiating antenna and the dummy antenna. The arc, of course, is common to both circuits also. The key K_1 obtains direct current from the line and energizes the solenoid which drives the key relay. When the key K_2 is used, switch Sw_4 must be closed, cutting out the dummy antenna circuit and connecting the main

radiating antenna directly to the arc converter at all times. The antenna circuit also includes a variometer for small frequency changes while calling, as well as two inductances with a continuously variable arrangement on one, and variable taps on the other. The condenser Ca is used for higher frequency radiation.

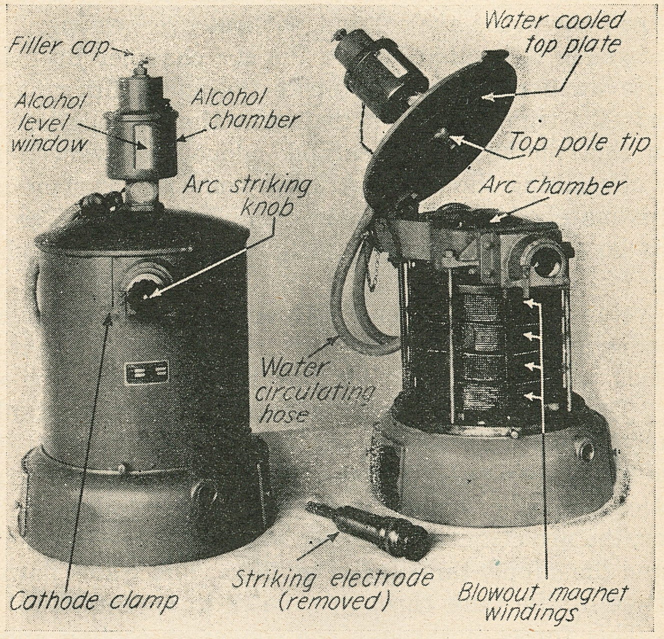


Fig. 19

The single loop of wire L_1 is coupled to the inductance L_2 of the antenna so that compensating wave keying may be used.

THE ARC CONVERTER

Figure 19 shows a complete picture of the arc converter and a view of the converter with the arc chamber open and the casing surrounding the blow-out magnets removed. On the top of the arc converter will be seen the alcohol chamber and the indicating window by which the level of alcohol may be determined. A cap is provided at the top of the alcohol chamber so that it may be filled. The water circulating hose is shown in both pictures.

The arc striking knob is shown near the top of the arc converter. It is a bakelite knob which can be moved in and out as well as rotated. To replace the cathode to which this striking knob is connected, the cathode clamp shown is uncoupled and the arc striking electrode is removed. The striking electrode is shown separately at the lower part of the picture. The blowout magnet windings are shown wound around the converter structure in four sections. They are made of very heavy wire so they can carry the arc current without overheating.

The anode is insulated from the arc chamber by means of a bakelite washer which must make the anode fitting air-tight and perfectly rigid. It is in line with the cathode but not in view in this picture. The cathode alone is advanced in the process of striking the arm. A 2 kw. converter carbon cathode is approximately ½ in. in diameter and 7 in. long. The copper anode is larger than this as it includes the water chamber for cooling.

A water supply tank for electrode and arc chamber cooling is placed above the converter. It is arranged so that water circulation will continue as long as the complete pipe system is full. Thus circulation will continue although the tank may be nearly empty. However, the tank should be kept full of chemically pure (distilled) water at all times to insure proper circulation. The complete water system includes the anode chamber, the arc chamber plates, a water flow indicator, a water pump and the supply tank (see Fig. 20). The water flows from the bottom of the tank through a valve to a centrifugal water pump. This forces it through the converter cooling apparatus through rubber hose which serves as an insulator. The entire water system is insulated from ground potential.

The model "Q"-2 kw. arc transmitter is equipped for use on all waves between and including 600 and 1200 meters. The 2 kw. arc chopper attachment can be used only on waves below and including 950 meters. On higher wavelengths continuous wave transmission must be used.

STARTING AND OPERATING THE ARC

Before starting the arc the following four points must be observed:

1. See that the alcohol cup is full and that the alcohol feeds into the converter chamber properly.
2. Make sure that the water supply tank is at least ¾ full of fresh distilled water.
3. Be sure that all the water valves in the circulating system are open and that the flow indicator shows circulation when the water pump is started.

4. See that all moving parts are properly lubricated.

The importance of these points cannot be over-estimated. Failure to follow them may result in serious damage to the transmitter.

The arc is now ready to start and the following is the procedure:

1. Close the main line supply switch.
2. Place the antenna changeover switch in "send" position. This closes a circuit which starts the water pump and carbon rotating mechanism.
3. Start the motor-generator by closing the circuit breaker on the starting panel and by bringing the motor gradually up to full speed with the starting lever. Adjust the generator voltage (250^v for a 2 kw. arc) by means of the generator field rheostat.
4. Start the alcohol flow so that it drips rather rapidly. Adjust the arc electrode spacing to 1/32 of an inch. The carbon electrode will move only this far when the arc is struck.

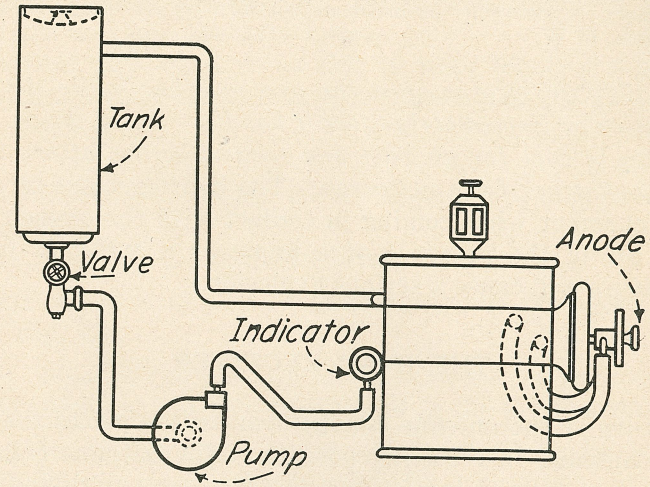


FIG. 20

5. Close the arc main line switch and strike the arc. The carbon holder is given a rather quick inward thrust by means of the hand. The hand should be removed immediately to allow the carbon to return to its original spacing. The arc is left this way for a minute or two during which time the electrodes heat up to operating temperature and the hydro-carbon gas is formed in the arc chamber. The arc will then start oscillating as indicated by the R. F. ammeter. The electrodes should then be separated by turning the carbon knob to the left until the meter shows that maximum antenna current is flowing.
6. Close the arc starting resistor switch and again adjust the arc electrodes for maximum antenna current. The alcohol flow should now be reduced to a few drops per minute and the generator should be adjusted to obtain the desired antenna current.

The chopper may be used either with the back shunt or the chopper key. To use the chopper with the back shunt method of signalling:

1. Throw switch S_1 in Fig. 18 to "up" position, thus closing auxiliary key circuit, and close double pole single throw switch S_2 to chopper. This connects chopper to compensating loop L_1 on the loading coil L_2.
2. Start the chopper motor by closing snap switch S_3.

3. Start arc as usual.
4. Signal with key K_1.

The chopper may also be used with the auxiliary key K_2. The following procedure must be observed.

1. Open switch S_1.
2. Close double pole single throw switch S_2.
3. Short the key K_1 to connect transmitter to antenna by means of switch S_4.
4. Start arc converter as usual and signal with key K_2.

Signalling may be done with the auxiliary key without using the chopper by the following procedure:

1. Throw switch S_1 to "down" position, thereby forming a closed circuit which includes the compensating loop L_1.
2. Close shorting switch S_4 which will connect the converter directly to the antenna, thus cutting out the back shunt circuit.
3. Start arc converter as usual and signal with K_2, radiating compensated C. W.

CAUTION: *Never open the arc chamber while the arc is in operation or immediately after it has been closed down. Allow electrodes to cool for at least one minute before attempting to open arc chamber for any reason.* The hydrogen gas formed in the arc chamber when coming in contact with the oxygen of the outside air in the presence of a flame or a sufficient ignition temperature will cause a serious explosion.

THE IP-501 RECEIVER

A turn of the antenna change-over switch places the transmitting antenna in receiving position. The antenna coil of the receiver is a tapped inductance so that along with the use of the series variable condenser the antenna circuit may be adjusted for various wavelengths. A test buzzer is capacitively coupled to the antenna lead by means of wrapping a few turns of insulated wire around the antenna lead leaving one end free. This is used for a test signal source. The secondary is composed of three sections, one to pick up the energy from the antenna circuit by mutual induction, one for wavelength adjustment (the loading coil) and a third to supply means for feeding back energy for regeneration. If it were not for the wide range of wavelengths which this set must be made to cover, one coil would serve the purpose of all three.

Fine tuning is done by means of the secondary variable condenser. The tickler coil is in two sections, one variable and one fixed so that a wide range of wavelengths can be handled. A link is provided to complete the plate circuit, and a shorting switch is provided so that the tickler coils may be shorted and

may be thrown out of use for reception of waves other than straight C. W. The rest of the circuit is quite familiar to you except perhaps for the closed circuit phone jacks provided in each stage so that trouble can be quickly located and so that no more stages or tubes need be used than necessary. The set as you may notice is in this case battery operated.

TEST QUESTIONS

Number your answers ~~2C~~ 2CA and add your *student number.*

Never hold up one set of lesson answers until you have another set ready to send in. Send each lesson in by itself before you start on the next lesson.

In that way, we shall be able to work together much more closely, you'll get more out of your course, and the best possible lesson service.

1. (a) Draw a diagram of a fundamental arc transmitter circuit.
   (b) Explain its operation briefly.
2. Explain the back shunt signalling system from the diagram in Fig. 10.
3. (a) What is the purpose of the blow-out magnets?
   (b) How are the pole tips placed in the arc chamber?
4. (a) Name two materials of which arc electrodes are made.
   (b) Why is one electrode rotated?
   (c) Why is water cooling of the electrodes necessary?
5. (a) What should the arc electrode spacing be just before the arc is struck?
   (b) What should the spacing be when the arc is in operation?
6. If a motor-generator stops while you are striking the arc, what may be the cause?
7. How would you reduce the radiated power of an arc transmitter?
8. Trace the antenna circuit of a back shunt arc transmitter, naming each part and giving its function in the circuit.
9. By what means may the frequency of the back shunt or dummy circuit be adjusted?
10. Draw a complete diagram of a 2 kw. arc transmitter including auxiliary battery supply, motor-generator and receiver.